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Augmented reality (AR) applications for supporting human-robot interactive cooperation

George Michalos[a], Panagiotis Karagiannis[a], Sotiris Makris[a], Önder Tokçalar[b], George Chryssolouris[a,]*

[a]*Laboratory for Manufacturing Systems and Automation, Department of Mechanical Engineering and Aeronautics, University of Patras, Patras 26500, Greece*
[b]*TOFAŞ TÜRK OTOMOBİL FABRİKASI A.Ş, Production Technology Development Department, Osmangazi Bursa 16369, Turkey*

* Corresponding author. Tel.: +30-261-099-7262; fax: +30-261-099-7744. *E-mail address:* xrisol@lms.mech.upatras.gr

Abstract

The paper presents an Augmented Reality (AR) tool for supporting operators where humans and robots coexist in a shared industrial workplace. The system provides AR visualization of the assembly process, video and text based instructions and production status updates. The tool also enhances the operator's safety and acceptance of hybrid assembly environments through the immersion capabilities of AR technology. A hardware landscape including the AR equipment and markers, the handheld devices for user input and the network infrastructure for interfacing the robot and the storage database is provided. The software architecture for coordinating the AR tool with the assembly process and the data retrieval from the robot controller are also presented. The tool has been tested on a pilot case in the automotive sector. The results indicate that the approach can significantly enhance the operator's working conditions and their integration in the assembly process.

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Keywords: *Augmented Reality; Hybrid Assembly System; Human Aspect; Robot.*

1. Introduction

Augmented Reality (AR) and Virtual Reality (VR) have made significant progress in the last decades, thus allowing for the creation of tools that can be considered for application in manufacturing practice. The main idea of VR is to create a digital world in which the user can be immersed and interact. In AR, the user can see the real world as well as digital objects superimposed over it. Manufacturing industries aim at reducing product defects, cycle time and related cost for reworking [1]. The AR technologies enable the users to visualize and interact with 3D objects more easily than they can through a simulation or a computer screen, making them more appropriate for cases that a) access to computers is not easy and b) the time for searching and acquiring assistance is limited[2]. This is why these technologies can be used in an industrial environment and help the manufacturers achieve their goals. VR has been used in the product assembly and maintenance [3] as well as in the product design [4, 5]. Furthermore, AR has been used in factory [6, 7] and assembly planning [8], in assembly guidance [9, 10, 11], in product design [10, 12], in assembly design [7, 8], in product maintenance [13] and in robot trajectory planning and simulation [7, 14].

However most of these approaches and especially the latter ones have been tested in laboratory environments, using either service and humanoids robots [15] or industrial robots [6, 14] but they have not managed to reach the production site with the exception of some small scale experimental installations, where only humans are active in the production process. Applications are presented in [3, 4, 5, 6, 7, 10, 11, 12, 13, 15].

Nevertheless, there are numerous industrial applications, where the assembly process is mainly performed by human operators due to the fact that a) operations require a human like sensitivity, b) there is a variation in the materials used often showing a compliant, unpredictable behavior (upholstery, rubber, fabric etc.) and c) frequently more than one operators are active in performing cooperative or parallel operations in each station [16]. The latest trends foster the co-existence of humans and robots under a collaborative environment, sharing both workplaces and tasks. The synergy effect of the robot's precision, repeatability and strength with the human's intelligence and flexibility [1] is great, especially in the case of small scale production, where re-configurability

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and adaptability are of great importance. Additionally, the introduction of robots to support assembly operators reduces the need for physical strength, especially in the cases of large part assembly, such as in the capital goods industry. Therefore, it is possible for older people to continue working inside the production facility, mostly having to undertake the cognitive tasks (coordination, troubleshooting etc.).

The AR tools should be enriched with further functionalities to support this collaboration in a user friendly way. The main aspects to be considered are the efficiency of the tools to match the industrial requirements as well as the enhancement of safety awareness by the operator so that he/she feels comfortable to work with a robot. This paper focuses on the assembly stage, where AR technologies can be used by the operators to:

- Receive information for each production step more easily and quickly, through virtual demonstrations, videos, instructions lists and images
- Receive visual and audio warning messages
- Visualize safety areas as well as the trajectory of the robot's end effector
- Acquire information on the shop floor status and the upcoming products, increasing his awareness and response in a non-intrusive way

This paper is aimed at presenting the implementation of AR support tools for operators inside assembly lines, where cooperation with industrial robots is carried out. The methods used and the experiments performed in a case study, stemming from the automotive industry are also presented. Section 2, provides a description of the proposed approach and the implemented functionalities. Section 3 describes the system's implementation in terms of the software and hardware components and Section 4, is dedicated to presenting the case study. Finally, in Section 5, the conclusions are drawn together with an outlook for future research.

2. Approach

The proposed approach aims at providing support through the visualization of different types of information, originating from different organizational levels (Figure 1). In this context, the AR application implements four main functionalities: assembly process information provision, robot motion and workspace visualization, visual alerts and production data. "Multiple visualization" means that tablets and AR glasses can be used in order to support the operator's work. At any point of time, the user can enable or disable these functionalities, through the interface buttons, with the exception of visual audio alerts that are pushed to his/her device automatically.

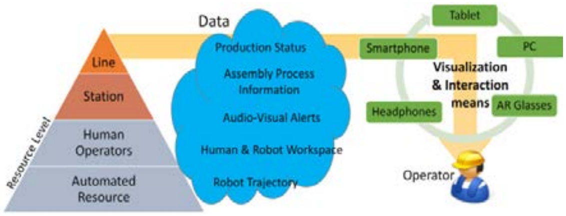

Fig. 1. Basic functionalities of the art of the AR support system

2.1 Operator Support - Assembly Process information

The main concept underlying this functionality is to assist the user in visualizing all the parts or components (in example screws, tools, glue etc.) and their assembly sequence in a more intuitive and comprehensive way i.e. by using 3D models. Since our paradigm considers multi-model products, the designed system should be able to automatically retrieve from the central database the correct CAD models and properly present them to the operator. An example is shown in Figure 2, depicting the assembly of a brake drum on a car axle. Additional information of the assembly process is provided in the case study of section 4.

2.2 Robot Motion and Workspace visualization

In industrial environments, where robots have to be in collaboration with humans, several safety risks (clamping, collision etc.) may be identified. For this reason, new generation robots, such as the COMAU C5G controller offer two safety functions: 1) interference regions and 2) safe cartesian motion. In the first case, inside the robot's controller, are stored the coordinates of 3D volumes that the robot is either constrained to working inside or forbidden to enter.

The motion is monitored by a certified system, based on double encoders. These volumes could be a cube, a sphere, a cylinder or a plane. In the second case, the controller ensures that the end effector should follow a precise path without any divergences.

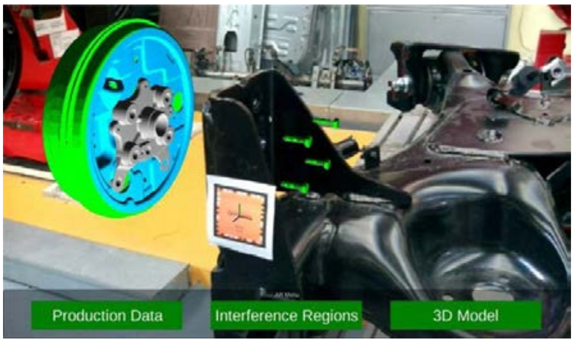

Fig. 2. Digital components superimposed on real world objects

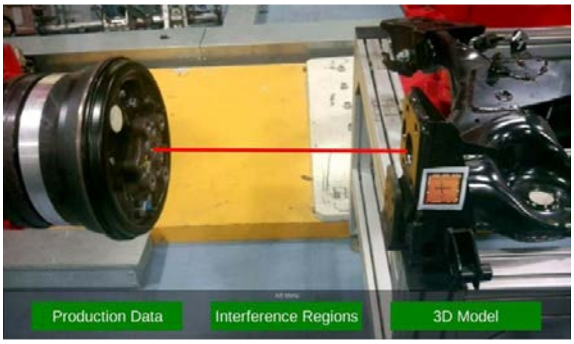

Fig. 3. Robot's end effector trajectory

All the above data are retrieved by the software system upon user's request as it is described in section 3.1. Processing is required for the transformation of the path and volumes coordinates into the AR system reference frame, in order for a correct visualization in terms of scale, position and orientation to be achieved. Examples of these cases are shown in Figures 3 and 4. In Figure 3, there is a marker used as reference to superimpose the trajectory of the robot (red line) over the actual image.

On the left side of Figure 4, there is a red semi-transparent cube, which represents the constrained robot's workspace for the specific assembly phase. On the right, there can be seen a green semi-transparent volume that signifies a safe area for the users' hands to be inside, during the assembly.

2.3 Visual alerts

Another functionality aimed at enhancing the safety and awareness of the operator involves the automated alerts that originate from the collaboration scheme between human and robot. The difference from previous functionalities is that these alerts are automatically triggered whenever an event with safety implications is triggered (e.g. when robot is starting to move in AUTO mode).

The content of these alerts involves:

- Robot start/stop motion
- Production line emergency stops
- Any other general alert designating by the process planner

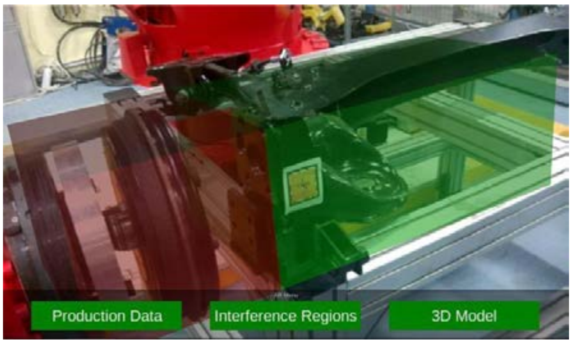

Fig. 4. Safety volume (green cube) and robot's working area (red cube)

Fig. 5. Warning messages

The added value of audio alerts is located in their usage for notifying the operators especially in case that they are focused on their tasks and may not pay attention to visual warnings. In the specific system the audio alerts are combined with visual alerts, appearing in the upper left corner of the user's field of view, as shown in the example of Figure 5.

2.4 Production data

Last but not least, the analysis of the industrial requirements has accentuated the need for transferring to the operators additional information, concerning the production status. These messages are informative concerning the current and upcoming models to be assembled, the average time remaining to the operator in order to complete his/her current task as well as the status of the successfully completed production stages, versus the targeted ones. Similarly to the case of visual warnings, these messages do not need markers to be presented to the user. Instead, they are triggered either manually when requested by the user or automatically by the system, when for example the time for the current action is about to end. In Figure 6, there is an example showing these messages on the upper right corner of user's field of view.

3. System implementation

The main challenge that had to be dealt with in this application was the diversity of cases and systems that had to work under the same system. In order for this difficulty to be

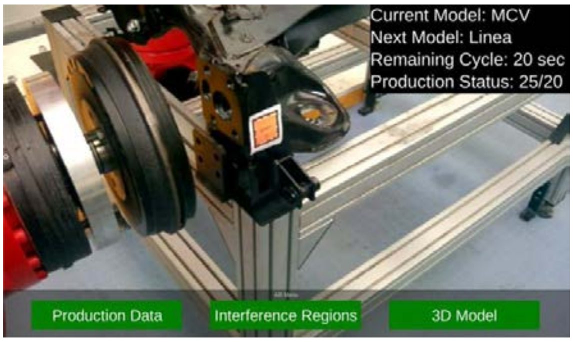

Fig. 6. Production information messages

overcome, a set of experiments that addressed the following technical challenges were performed:

- Marker placement in space and recognition by the camera.
- Multi-model visualization in space upon marker's recognition.
- Coordinate transformation from robot-based coordinates to marker-based ones.
- Correct placement and visualization of messages/alerts
- Communication through the Robot Operating System (ROS) for higher versatility
- Communication with the main database, which contained all data and CAD files
- Application execution on desktop PC with web camera
- Running the application on an android tablet.

3.1. Software tools

This application is created in Unity3D game engine [17] using some auxiliary libraries and some custom C# scripts. More specifically, the marker recognition and model visualization are handled by Qualcomm's Vuforia library [18] which runs on Unity3D. This library offers quick, multiple marker recognition and extended recognition, meaning that the system can visualize digital objects correctly even when the marker is no longer in the camera's field of view. Another library used was the JSON library [19] which handled the package exchange with the ROS topics. Finally, for the development of this application some C# scripts were written to perform several tasks such as:

- the model, trajectory and interference region's visualization in the correct place,
- the representation of production data and warning messages,
- the connection with ROS for message exchange,
- the connection with the main database to download the necessary data and
- the creation of a menu enabling the operator to show or hide the visualized data.

3.2. Hardware tools

Despite the project's complexity, the systems' hardware is simple and thus easily deployable. The topology is shown in Figure 7. For the early versions of the application, a simple web camera, connected to a laptop, running the application, was used. The results were visualized on the laptop screen.

In addition to this, a MySQL server in order to run the MySQL database was set up on the same system, whilst the ROS was set up on an Ubuntu virtual machine. Following the building of the android application, through the Unity system, a single tablet (ASUS Transformer Prime TF 201 running Android 4.1.1) was used in order for all functionalities to be performed by the user through the on-screen buttons.

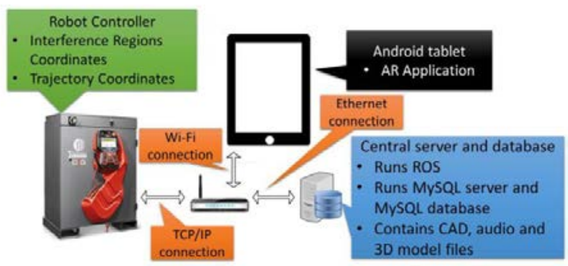

Fig. 7. System Implementation

4. Case study

The case study tested by this application originates from the automotive industry and has been applied to the robotics cell that is shown in Figure 8. A high payload robot (COMAU NJ 370) is used in order to load the 25 kg axles on the fixture and to support the human by holding the rear wheel groups in the assembly area. The axle loading is solely carried out by the robot in the automatic mode, while the wheel group assembly requires the cooperation between the robot that carries the weight (10-12 kgs) and the human, who uses his hands to directly adjust the position of the parts. The heaviest part lifted by the operator in this scenario is that of the screwdriver (1.5kg). While the human performs delicate tasks (cable assembly), the robot continues bringing the second wheel group, avoiding any collision with the human.

In the application, which runs on an android tablet, the operator can visualize through the touch screen all the functionalities analyzed in Section 2. Using the menu buttons, which are visible at the bottom of the screen as it is presented on the previous figures on Section 2, he/she can enable or disable any of the visualized objects, which are pre-downloaded from the main server on the device.

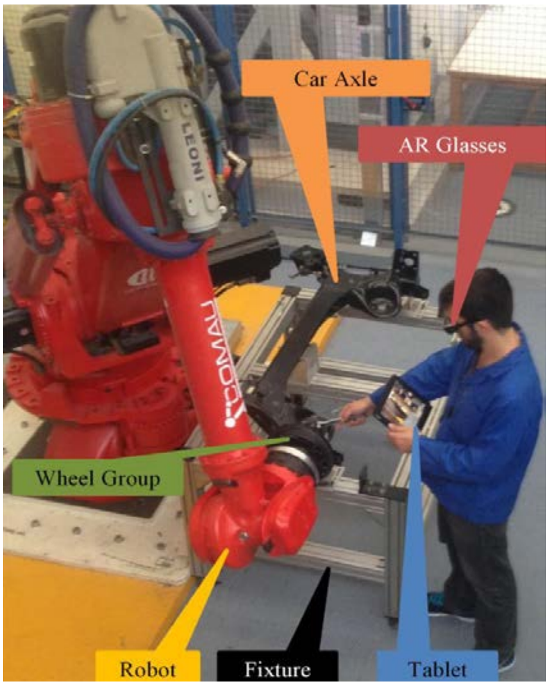

Fig. 8. The cell where the automotive scenario took place

Fig. 9. Multi-model visualization of the pre-downloaded assembly models

Alternatively, as it is shown in Figure 8, the user can use AR glasses to run the same application. Furthermore the user can view more than one assembly models, depending on the production stage. An example is shown in Figure 9, where the user can visualize either a rear wheel assembly or a brake drum assembly on the same axle.

5. Conclusions

This paper presented an AR based application that ran on an android tablet, to support human-robot interactive cooperation in an automotive environment. The two main goals to be achieved by this application are to enhance human safety and increase its productivity in an industrial environment, where robots co-exist with humans. Multiple functionalities involving the visualization of safe working volumes, the provision of production related data, the enablement of visual/audio alerts as well as the representation of the robots motion, have been implemented in this direction. The first experiments have validated the ease of deployment and applicability of the systems with the use of a simple PC setup or a handheld tablet.

Further research should focus on the integration of lightweight AR glasses. The current solution (the use of the tablet) is not optimal for an industrial environment, because it requires the user's both hands for interaction that compromises the assembly process. Apart from this, the user wastes time upon checking the necessary info through the tablet and then proceeding with his task. As an alternative, when using AR glasses, all this info is presented to his field of view in real time and in parallel with his work. In other words, the use of a tablet has a negative impact on the operator's comfort, in the production lines, with further delays in the production process.

In addition to this, more research should be done on the more ergonomic design of the support provided (colors, transparency levels etc.). Visualization without markers can be used in order to avoid fill in the space with many markers. Instead, one can use the object itself as a means of recognition. The user has one object, on which he/she already works. Furthermore, in the direction of ergonomic design, certain adjustments should be applied to the visualized objects to prevent jitters and vibrations. Due to environmental issues and the quality of devices the recognition process of the markers is not always very robust, thus leading to minor position alterations in each frame. This makes the 3D models to shake, increasing user's discomfort. For that reason, certain methods for the fine tuning of these alterations should be applied.

The integration with legacy systems to automatically retrieve all CAD data and production information also needs to be investigated. Apart from this, the necessary data should be retrieved in a more intuitive way by associating each production phase with certain functionalities. To this effect, the user will automatically request from the system all the data required for each phase and not manually that would result in the loss of time

Last but not least, more efforts need to be made for the extension of this application to other industrial environments, where the human-robot interaction is necessary. In this direction, the system can be updated with extra functionalities, depending on the particularities of each individual production sector.

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